The Determination Of The Microphysical Characteristics Of Aerosols In The Lower Part Of The Marine Atmospheric Boundary Layer From The Structure Of The Backscattered Lidar Signal

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LONG-TERM GOAL

The long-term goal is to develop an efficient methodology for determining the aerosol optical properties from environmental factors (such as wind, temperature, humidity, waves, etc.) in the lower part of the marine atmospheric boundary layer (LP MABL).

OBJECTIVES

Our objective is to develop a method for determining the aerosol microphysical characteristics in LP MABL from the backscattered lidar signal (BLS). This-year objective is to extend the previously constructed inversion algorithm to a wider class of aerosol particle size distributions (APSD), and to test the validity of the inverse method by experimental lidar data obtained by the group of Dr. S. Sharma of the Hawaii Institute of Geophysics and Planetology (HIGP).

APPROACH

Last year, we developed the method of mean ordinates for inverting scarce or/and incomplete aerosol optical data into the aerosol microstructure. The method proved to be particularly efficient in inverting the aerosol optical characteristics obtained from lidar observations. The essence of the method is as follows [1]:

- The APSD is described by a sum of lognormal components representing small-sized, medium-sized, and large particles. The aerosol parameter intervals are intentionally preset so wide that all known types of atmospheric aerosol are included into consideration.
- The APSD parameters are quantized on the specified intervals. All possible combinations of the quantized parameters are selected by exhaustion, and an APSD is constructed for each combination.
- Optical characteristics of each constructed model are calculated and compared with the data to be inverted (initial data).
- The models whose optical characteristics coincide with the initial data within preset error intervals

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are considered as acceptable solutions.
- The mean ordinates of APSD over the ensemble of all acceptable solutions are calculated.
- The model closest to the curve of the mean ordinates is taken as the most probable solution.

The method was tested by numerical experiments on inverting aerosol optical characteristics obtained from one-lidar or two-lidar observations [1]. The results proved to be quite satisfactory for smooth enough APSDs. In this respect, as well as in terms of accuracy, the method of mean ordinates is comparable to the constrained inversion method. During this year, we have studied the applicability of the method to a wider class of APSD including components of rather narrow distributions.

The method of mean ordinates has been employed in the analysis of experimental lidar data obtained at HIGP [2,3]. Horizontal profiles of the aerosol spectral attenuation were determined. For this purpose, we resorted to the numerical solution of the basic differential lidar equation [4]. The relationship between the aerosol spectral attenuation σ and backscattering coefficient β was assumed to be $\beta = \text{const} \times \sigma^k$. A stable solution was attained by specifying the boundary condition as a value of the spectral attenuation far from the source. It was calculated by the slope method on some distance range.

APSD was determined for some representative points of σ profiles. They were analyzed in terms of the behavior of particle concentration and with respect to the shape of APSD along the profiles.

WORK COMPLETED

The last-year results showed that the method of mean ordinates works quite well (with an error of 15-25%) for one or two lidars provided the sought-for APSD is smooth enough. The smoothness of an APSD curve can be characterized by the dispersion of APSD components. The APSD curve is sufficiently smooth when the dispersion is greater than 0.2. When the dispersion is less than 0.2 (narrow peaks), data of one or two lidars are inadequate to achieve a satisfactory accuracy of the retrieved APSD. At some spectral ranges, the retrieval error for the spectral attenuation may be as high as 60%.

We applied the method of mean ordinates to APSDs containing narrow peaks (0.1-0.15 dispersion). We considered three-lidar data at 0.55, 1.06, and 10.591 μm, and four-lidar data at 0.55, 1.06, 4.7, and 10.591 μm. It turned out that even for three lidars, the inversion results are promising: the height and position of the peaks are represented quite accurately. The results on the peak width are less precise. The retrieved peaks are wider than the initial ones. Notwithstanding these discrepancies between the initial and retrieved APSD, the aerosol optical properties are represented quite accurately. The mean (over the whole 0.45-15 μm spectral range) error of the retrieved spectral attenuation is 4%. The maximum error does not exceed 16% (at 7.2 μm).

The use of four lidars yields still better results. In this case, the difference between the initial and retrieved spectral attenuation does not exceed 1%.

The results of the inversion of three-lidar data obtained by the method of mean ordinates are shown on Fig.1a,b.

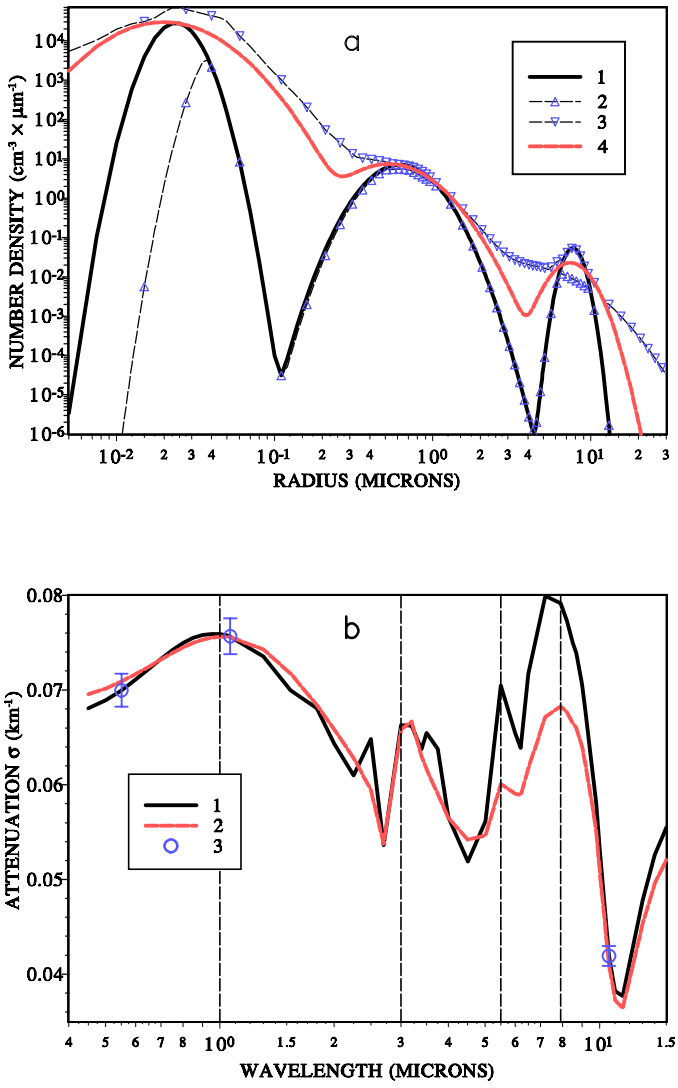

Fig.1. a):APSD; 1, initial APSD; 2,3, minimal and maximum ordinates; 4, the most probable APSD; b): the spectral attenuation σ; 1, initial σ; 2, σ calculated for the most probable APSD; 3, reference values of σ.

We calculated profiles of the spectral attenuation from horizontal lidar data at 0.532 μm. The observations were carried out by the group of Dr. Sharma of HIGP on the Coconut Island, Hawaii, in October 1997. The σ profiles showed significant spatial irregularities of dimensions of 100-400 m. In some cases, their optical thickness was as high as 0.27. The irregularities took place against the background of a general increase of σ in the seaward direction.

Using the method of mean ordinates, APSD was calculated at some representative points on the σ profiles. Fig. 2 shows a profile of σ for a lidar scan on October 16, 1997. The points for which APSD were determined are marked by numbers.

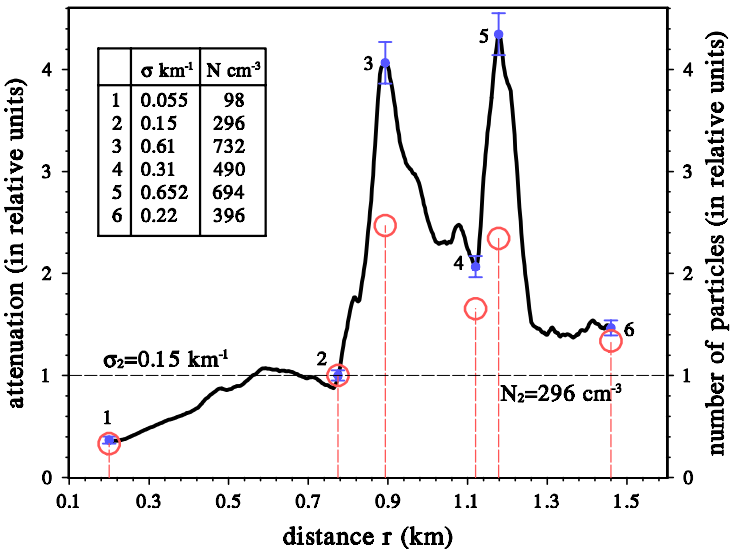

Fig.2. Profile of the spectral attenuation σ. Six points with error bars (±5%) for which APSD were retrieved are marked by numbers. Circles show the total number of particles (per cm^{-3}) related to the numbered points. All quantities are normalized to the corresponding values at point 2.

In order to unify all the data for the further comparison, they were reduced to those at the point 2 (corresponding to the background value of σ). Circles mark the values of the total number N of particles. It is seen that at the points 1, 2, and 6 variations of σ are associated with variations of N while the shape of APSD changes only slightly. In the case of inhomogeneities (points 3,4,5), the increase of N cannot completely account for the increase of σ. Clearly in this instance, the shape of APSD changes significantly.

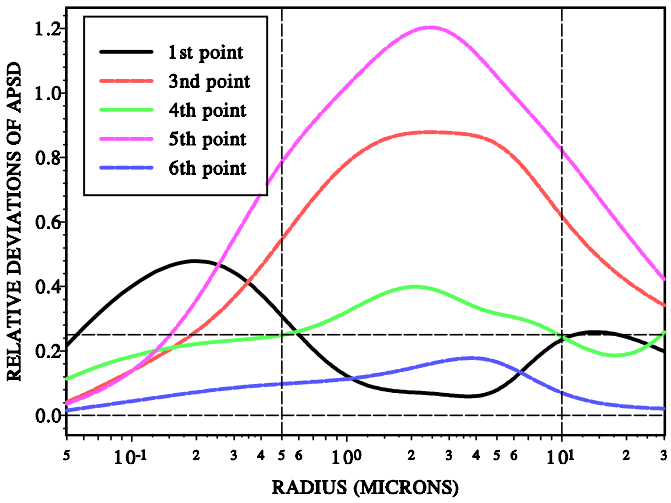

Fig.3. Relative deviations of APSD at the numbered points from APSD values at point 2.

Fig. 3 shows relative deviations of APSD (in reference to the APSD at point 2) normalized to one particle. It is seen that at the points 3,4,5, the APSD has a noticeable hump on the optically active 0.5-10 μm particle size interval, as compared to the "background" APSD at the point 2. This accounts for the behavior of σ within the inhomogeneities. In contrast to this picture, deviations of APSD at the points 1 and 6 remain within 25% on the active size interval. Noteworthy, the number of small particles at the point 1 is noticeably higher than at the point 2. In other words, the relative content of small particles recedes from the coastline in the seaward direction.

RESULTS

1. It was established that the use of greater number of lidars (more than two) significantly extends the efficiency of the method of mean ordinates for inverting lidar data into APSD.
2. It was confirmed that significant inhomogeneities of aerosol optical properties take place in the Hawaiian coastal zone. Using the method of mean ordinates, we estimated the magnitude and character of these inhomogeneities in terms of the total number of particles as well as with regard to variations of the APSD shape.

IMPACT/APPLICATION

The method of mean ordinates proved its efficiency in inverting lidar data into the aerosol structure. It has been tested both by numerical experiments and by real lidar observation data. The impact of these results is quite significant. Considering the fact that the conventional inversion methods fail when applied to lidar data (because of a limited number of observation wavelengths), the method of mean ordinates is currently the only one to efficiently utilize lidar information for marine aerosol studies.

TRANSITIONS

The method of mean ordinates is used in our joint work with the experimental group of Dr. S. Sharma of the Hawaii Institute of Geophysics and Planetology for the analysis of lidar measurement results and for studying the aerosol structure in LP MABL in the Hawaiian coastal zone. In the near future, the investigations will include nephelometer measurements by Dr. A. Hunt of the Lawrence Berkeley National Laboratory. The method of mean ordinates has been employed by Dr. P. Bruscaglione, Instituto Fisica Superiore, Italy, for studying atmospheric aerosol near the sea surface; by Dr. O.V. Kopelevich, Institute of Oceanology of the Russian Academy of Sciences, for hydrosol studies; by Dr. J. Lenoble, Laboratory of Optics of the Atmosphere, Universite des Sciences et Technologie de Lille, France, for studying atmospheric aerosol.

RELATED PROJECTS

The approach developed in the method of mean ordinates for inverting scarce or incomplete data is being used in our NASA-funded project "The improved algorithm for estimating the atmospheric effect in space measurements of the chlorophyll concentration."

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